

Impact Testing for Materials Science at NASA - MSFC

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Abstract

The Impact Testing Facility (ITF) at NASA - Marshall Space Flight Center is host to different types of guns used to study the effects of high velocity impacts. The testing facility has been and continues to be utilized for all NASA missions where impact testing is essential. The Facility has also performed tests for the Department of Defense, other corporations, as well as universities across the nation. Current capabilities provided by Marshall include ballistic guns, light gas guns, exploding wire gun, and the Hydrometeor Impact Gun. A new plasma gun has also been developed which would be able to propel particles at velocities of 20km/s. This report includes some of the guns used for impact testing at NASA Marshall and their capabilities.

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I. Introduction

The Impact Testing Facility (ITF) at NASA - Marshall Space Flight Center is the heart of materials science testing for both new and existing materials around the world. Nationally, since its establishment, the Impact Testing Facility at Marshall has been an asset for NASA's missions, for the Department of Defense (DoD), private corporations, and universities across the nation. Internationally, the ITF has performed tests for the European and Russian space agencies in support of the International Space Station.

With the advancement of future materials and the field of materials science, scientists all over the world are constantly looking for ways in which to test these new technologies in different conditions. Materials testing vary from type of material being tested, its application, and environment of the test. It is with the strict requirements in Aeronautics and Aerospace industry as well as the DoD requirements and other industries that the impact testing facility at NASA Marshall has been at the forefront of improving testing capabilities by developing new, state of the art technologies that simulates the types of conditions that the material being tested would encounter.

Material samples are tested in conditions such as space with micrometeoroids or even atmospheric environments with rain conditions, where the micrometeoroid particle or rain drop effects of high velocity impacts are replicated.

Safety is the major reason why impact testing in materials science is very critical. The actual performance of a material varies drastically from predictions made when only looking at the materials properties. The variation is more significant when dealing with high velocity impact since the Kinetic energy associated with the moving mass increases by a power of 2 as seen in equation 1 below.

$$K_e = \frac{1}{2}mv^2 \quad (1)$$

Where K_e is the kinetic energy, m is the mass, and v is the velocity

As the Columbia accident teaches, there is no substitute for testing. It is from lessons learnt from such accidents as space shuttle Columbia that testing of materials has to be done to mimic expected operational conditions.

Working in compliment with other NASA centers like White Sands, Marshall ITF has been working diligently providing NASA and other agencies the necessary testing capabilities to ensure safety and successful designs for both existing and future technologies. Technologies that will be critical to NASA future missions as well as technologies used in defense as well as in our domestic lives.

One of the technologies currently being tested at NASA Marshall Space Flight Center ITF is the thermal protection shielding material for Aerocapture Technology.

²Aerocapture technology is a flight maneuver that inserts a spacecraft into orbit around a planet or moon by using the destination's atmosphere like a "brake." The dense atmosphere creates friction, which is used to slow down a craft, transferring the energy associated with the vehicle's high speed into heat. This allows for a quick orbital capture without the need for a heavy load of on-board propellant, which increases launch cost.

This maneuver requires entry and exit of the target body's atmosphere from a hyperbolic approach trajectory to the desired elliptical orbit using the target body's atmosphere as a brake. The Aerocapture maneuver would encounter lots of energies as well as different kinds of micrometeoroid impacts from space and other particles from the atmosphere. It is therefore the aim of Marshall ITF and other NASA testing facilities to simulate these conditions and test proposed materials. At Marshall, samples are chilled and sometimes radiated before they are impacted with glass particles at velocities of 7km/s or higher. Glass impacts give a comparable representation of a micrometeoroid impact. A new gun that utilizes electromagnetically accelerated plasma to propel particles to velocities of up to 20km/s is also under development at NASA Marshall Space Flight Center.

It is with requirements as extensive as with Aerocapture that other industries also utilize the capabilities of the Impact Testing Facility at Marshall.

² (For Fuel Conservation in Space, NASA Engineers Prescribe Aerocapture, 2006)

II.

Hypervelocity impact testing capabilities

Below are the hypervelocity impact testing guns currently at Marshall Space Flight Center. Hypervelocity guns have the capabilities of reaching velocities much higher than 2.5km/s

Light Gas Gun (LGG)

The Light Gas Gun (LGG) has been operational since the 1960s and is the oldest gun at Marshall. The LGG has the capability of customizing the barrel diameter to up to 19mm as well as two different size chambers, 1m and 3m, that could be utilized depending on the sample size. The gun has been used to test Whipple shield designs, a design used on many spacecrafts. This gun has also been used to test debris shielding for the international space station as well as tests for the European and Russian space agencies. The LGG is the father of the MLGG. The LGG is capable of firing 2mm to 19 mm projectiles at velocities of 2.5km/s to 7.5 km/s. Figure 1 below shows the Light Gas Gun at NASA - Marshall Space Flight Center.



Figure 1. Light Gas Gun (LGG)

Microlight Gas Gun (MLGG)

The Microlight Gas Gun (MLGG) has the capability of firing projectiles of diameter between 0.2mm to 1.0 mm at velocities of 3km/s to 7km/s (Mach 9 to Mach 21). The MLGG has been used to test $0.9\mu\text{m}$ thin solar sail material that has been embrittled by radiation. Sulfur concrete was also tested with the MLGG during investigations of building a permanent Lunar base. This gun has also been used to test orbital micrometeoroid debris shielding materials , self-healing plastics, etc. The projectile from this gun breaches into a vacuum tube where it free flies into the vacuum chamber where samples are placed. Studies and design changes are currently under way to perform customized impact tests for Aerocapture thermal protection system material where the samples are to be chilled to about 90K and impacted with glass at about 7km/s. Figure 2 shows the Microlight Gas Gun.



Figure 2. Microlight Gas Gun (MLGG)

Exploding Wire Gun (EWG)

The Exploding Wire Gun (EWG) is capable of achieving velocities of up to 7km/s for 0.4mm to 4.0mm particles. This gun is capable of firing glass, nylon, and aluminum projectiles. Single or multiple projectiles can be fired with the EWG. The figure below shows the Exploding Wire Gun



Figure 3. Exploding Wire Gun

Marshall Micrometeorite Gun (MMG)

The Marshall Micrometeorite Gun has the potential of firing 5 to 200 μm particles at velocities of up to 20km/s in vacuum. This gun can be used to test the effects of micrometeoroid impacts in different conditions. The figure below shows the Marshall Micrometeorite Gun. This is the fastest gun in the United States if not the world.

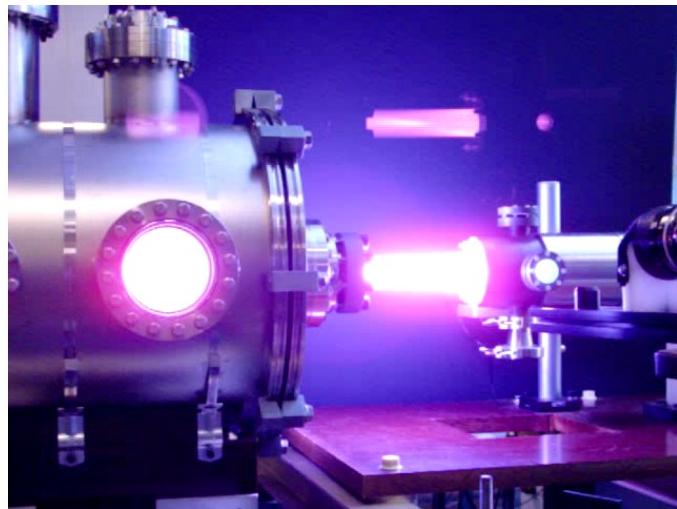


Figure 4. Marshall Micrometeorite Gun

III. Ballistic velocity impact testing capabilities

Below are some of the guns for ballistic impact. These are impacts of max velocities of about 2km/s

Large Ballistic Gun (LBG)

The Large Ballistic Gun can fire projectiles with diameter of up to 63mm to speeds of about 600m/s. Located on the outdoor range, this gun can be used to fire on full-scale flight hardware. The LBG has been used to test thermal protection debris on the SSME nozzles. Below is the figure of the Large Ballistic Gun at Marshall.



Figure 5. Large Ballistic Gun (LBG)

Small Ballistic Gun (SBG)

The Small Ballistic Gun is modeled after the Large Ballistic Gun. It can fire projectiles of up to 30 mm at velocities of 15m/s to 450m/s. The SBG was used during the investigation of the hydrogen valve failure investigation for STS-126 as well as for computer model validation of the space shuttle launch debris. There is an even smaller version of the ballistic gun called the Microballistic Gas Gun (MBGG) which is capable of firing 2mm to 4mm diameter projectiles at velocities of up to 914m/s.



Figure 6. Small Ballistic Gun (SBG)

Single-Particle/Multiparticle Impact Gun (PIG)

The Single-Particle/Multiparticle Gun can be used to simulate environment conditions that have particles of different sizes and shapes. It's able to fire these particles or single particle at velocities of up to 1.8km/s. The particles vary in size from 0.01mm to 5.00mm. The figure below shows the Single-Particle/Multiparticle Gun.



Figure 7. Single-Particle/Multiparticle Impact Gun (PIG)

Microballistic Powder Gun (MBPG)

The Microballistic Powder Gun has a very fast turnaround time (time needed to set up for each shot) and has very high accuracy. The gun is able to fire bead sizes of 2mm to 4mm diameter by using customized barrels. This is the most frequently used gun because of its accuracy and turnaround time. The Gun fires polymeric beads at velocities of up to 1.8km/s. As is with most guns at the ITF, high speed cameras, photo diodes, lasers, etc are used to measure the velocities of projectiles. The polymeric projectiles are used to simulate rain impact. The figure below shows the Microballistic Powder Gun.

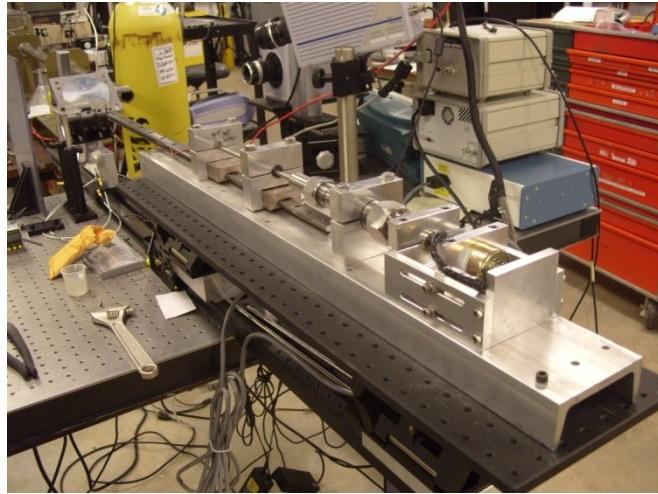


Figure 8. Microballistic Powder Gun (MBPG)

Hydrometeor Impact Gun (HIG)

Also known as the “Rain Gun” unlike most guns where the sample is stationary and impacted, with the Hydrometeor Impact Gun, test samples are fixed inside a sabot at the desired angle and fired into a single free falling water drop. Samples are fired into a drop of water at velocities of 0.09km/s to 1.4km/s depending on the sample mass and customer requirements. This gun has been used for weather encounter testing by the DoD and is considered a national asset. The figure below shows the Rain Gun found at NASA Marshal Space Flight Center Impact Testing Facility.



Figure 9. Hydrometeor Impact

IV. Discussion

With all the different kinds of guns at the NASA Marshall Space Flight Center Impact Testing Facility, flexibility on what is to be expected or required from a customer is a must. Each material that comes into the Impact Testing Facility has its own unique testing requirements that are designed to meet applications. Requirements for tests might include a combination of vacuum, cryogenic, specific angle of impact, required velocities, projectile size, sample size, etc. It is therefore the job of the testing engineers to design test conditions and set up to meet customer requirements. Communication is very important in testing. There are times when customers are not able to share the applications of the material being tested and so it is very crucial that we verify with the customer about every aspect of the test set up. Data are collected using photo diodes, time of arrival sensors, lasers, high speed cameras, etc. This data is analyzed and verified with expected values.

The Impact Testing Facility at NASA Marshall has been working on designs to conduct impact tests for the Aerocapture project. It is very crucial that the required conditions are met before tests can be conducted on the Aerocapture thermal protection samples. Design and Development is done for all the contracts that come to the Impact Testing Facility at Marshall.

V. Conclusion

Testing is required for safe design and mission success. NASA has conducted impact testing on manned and unmanned flight external hardware at NASA Marshall Space Flight Centers Impact Testing Facility. Depending on application and environment, each test has unique testing conditions. Research and development is necessary to improve testing capabilities.

NASA USRP – Internship Final Report

VI. List of References

NASA NP-2010-05-73-MSFC

“For Fuel Conservation in Space, NASA Engineers Prescribe Aerocapture” Marshall Space Flight Center, Alabama, August 2006, [<http://www.nasa.gov/vision/universe/features/aerocapture.html>. accessed 12/10/10]

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